ECL 107A

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BENEFIT-COST ANALYSIS APPLIED TO AIR POLLUTION CONTROL

A Case Study Based on the

Dixon, Tiller County/U.S.A. Reference Community

Part A: Problem Statement and Other Data

 Written by Professor G. A. Fleischer, University of Southern California, Los Angeles, with financial support from the National Science Foundation.

FOREWORD

This case study is based on the *Dixon, Tiller County/U.S.A. Teaching Reference Community* developed by the National Communicable Disease Center of the U.S. Public Health Service. The original set of documents associated with this project was developed to be used in teaching public health principles in the Center's Training Program, but it has since been used by a variety of institutions elsewhere in the United States.

The City of Dixon is a pseudonym for an actual community in the southeastern part of the United States. However, the National Communicable Disease Center wishes to protect the identity of that community, and thus we are unable to identify it further here.

Upon this "real world" community, we have superimposed a fictionalized account of a problem ephasizing the engineering-economic analysis of technical alternatives in a marked socio-political environment. The problem has been developed in cooperation with the Air Pollution Control Institute of Southern California and validated in three of its training programs. The participants in these programs include engineers, public health specialists, public administrators and others with extensive experience in roles similar to those described in the case study, and thus we have been able to insure that incidents described in the case have, in fact, had "real world" counterparts.

Although the data provided in Part A of this case study should be sufficient for solution of the problem described therein, the reader may be interested in additional data provided by *Reference Community* documents. These are:

Ref. No.	*Title*
300.000	Dixon, Tiller County/U.S.A.: A Teaching Reference Community. (This is the basic publication describing the simulated community.)
300.003	Population and Housing: Census Tracts, 1960, Dixon and Fernville.
300.004	Census of Housing, 1960: City Blocks, City of Dixon.
300.005	Census of Housing, 1960: Special Reports for Local Housing Authorities, Dixon, U.S.A.
300.300	Medical Profile.
300.006	Morbidity, Mortality, and Vital Statistics: Dixon, Tiller County/U.S.A., The State, 1940-1965.
300.007	Health Interview Survey.
300.200	Rules and Regulations Governing Nursing Homes and Related Facilities.
300.105	Lake Orlie Environmental Sanitation Survey.
300.008	Description of Basic Publications.

Additionally, there are certain supplementary materials, e.g., 2x2 slides, a 16 mm. sound movie, and special maps. All correspondence should be directed to:

National Communicable Disease Center
Bureau of Disease Prevention and Environmental Control
Public Health Service, U.S. Dept. of H.E.W.
Atlanta, Georgia 30333

The case study is organized into two sections: Part A, Problem Statement and other data; and Part B, Analysis. It is recommended that Part B be withheld from the students until they have had the opportunity to attempt their own solution, although the sections may be discussed consecutively if sufficient time is not otherwise available.

The "Additional Problems" included at the end of Part B are intended primarily to encourage discussion about simplified assumptions and uncertainty associated with data estimates. (Question 8 illustrates the "ranking error" which occurs so frequently in connection with the Benefit-Cost Ratio Method.) These problems may be omitted without interrupting the continuity of the presentation.

[Professor J. M. English of U.C.L.A. has suggested several problems which would encourage discussion of the case in a broader context. For example, how might the contribution of other pollutants, such as the automobile, be related to "damage costs"? What about the long range projection of purchased power? (i.e., if the present cost is only 15% above city costs what will be the situation in a few years?) Should benefits which extend beyond the area of Dixon be evaluated and if so, why?]

The Compound Interest Tables, using an effective interest rate of seven per cent, are included (as Appendix A-2) for the convenience of the student. Similar tables are available in a variety of references, for example, mathematics and statistics handbooks as well as engineering economy or economic analysis texts.

As a final note, the following item appearing in the November 29, 1967, issue of the *Los Angeles Times*, is of interest:

> "Purchase of 165,000 barrels of low-sulfur oil for use in a Seal Beach electricity generating plant was approved Tuesday by the Los Angeles Water and Power Commission.
>
> "The fuel, which produces less smog than the high-sulfur content oil normally used, will be burned at the Department of Water and Power's Haynes generating plant.
>
> "It costs $2.55 a barrel. High-sulfur content fuel costs $1.45 a barrel, said Edgar L. Kanouse, DWP general manager and chief engineer."

G.A.F.
Los Angeles
August 1968

PROBLEM STATEMENT

Community[1]

Tiller County is located on the westerly boundary of the State, approximately 25 miles north of the Atlantic Ocean. Commerce of the County is agricultural and industrial; the former being in the rural areas and the latter in the more thickly populated urban area. (A map of the County is shown as Figure A-1.) The area of the County is about 248 square miles. The total County population according to the 1960 census was 158,623.

The County is governed by a five-member Board of Commissioners of Roads and Revenues, each member elected for a staggered term of four years. The only qualifications for membership on the Board are (a) the candidate must be at least 25 years of age, and (b) he must be a qualified voter for at least two years prior to running for the office. Finances and personnel are administered by the County Clerk, who reports to the Board.

Fort Battle, a military reservation, occupies much of the southeastern portion of the County. This fort covers a total area of 286 square miles, only 79 of which are in Tiller County, yet, since the main part is in the County, there were (in 1964) about 65,000 military personnel and their dependents living in the County.

The *City of Dixon,* county seat of Tiller County, is a riverport city located in the western portion of the County. The metropolitan area includes 25 square miles and contained 135,000 people at the time of the last local census (1964). The City is located on the Keener River, approximately 25 miles from the Atlantic Ocean, and directly across the river to the west is Fernville, a community of about 30,000 (as of 1960). The textile industry is the principal source of employment in the area, although other important industries include food processing, lumber, chemicals and fertilizers, stone, clay, and glass products. The population growth of the City and the County is reflected in Table A-1.

The administration of the city government is in the hands of a City Manager appointed by a five-member City Commission for an indefinite term. The Commissioners are elected for four-year staggered terms every two years. Currently (i.e., in early 1967), the Commissioners and the City Manager are as follows (the dates of expiration of the current terms are shown in parentheses):

Carl Anchor	(1968)
Gary Fletcher, Chairman	(1968)
Gilbert Foy	(1970)
Jack Hazeltine	(1968)
Charles Winston	(1970)

and

George Siegel, City Manager

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[1]This problem based on the Dixon, Tiller County/U.S.A. Teaching Reference Community, U.S. Department of Health, Education and Welfare, Public Health Service, Communicable Disease Center, Atlanta, Georgia 30333.
See Foreword for additional discussion.

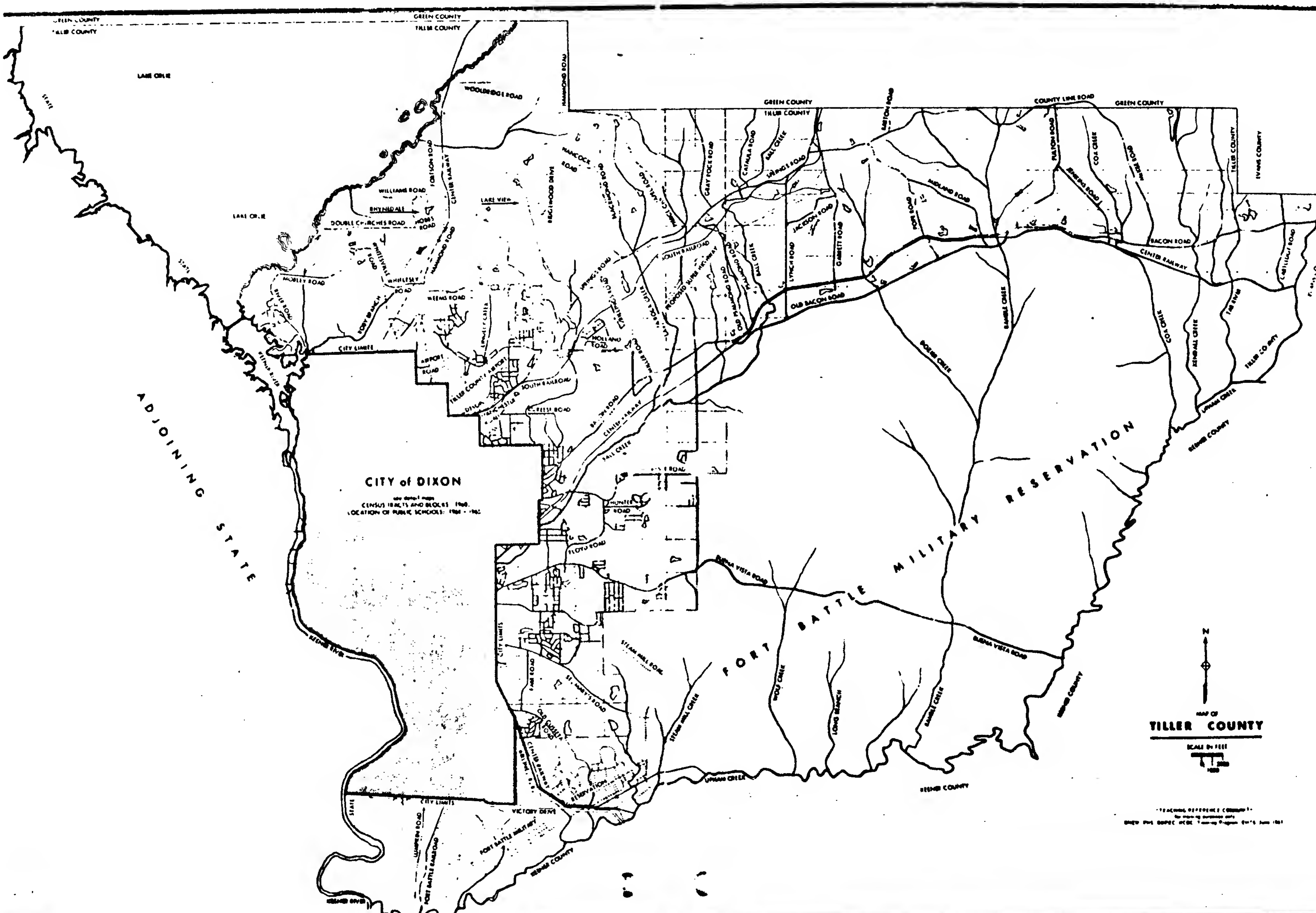

Fig. A-1 Map of Tiller County

TABLE A-1

PAST, PRESENT, AND ESTIMATED FUTURE POPULATION

DIXON AND TILLER COUNTY

Year	Dixon	Tiller County*
1890	17,303	22,871
1900	17,614	29,836
1910	20,554	36,227
1920	31,125	44,195
1930	43,131	57,558
1940	53,280	75,494
1950	79,611	115,000
1960	116,779	158,623
1964	131,600	181,000
	(Projected Population)	
1968	140,000	185,000
1970	148,000	188,000
1980	179,000	222,000
1990	210,000	252,000
2000	242,000	284,000

* Population of Tiller County includes the City of Dixon

George Siegel received his B.S. in Economics from Stanford University in 1954 and, after a period in the Navy as a commissioned officer, received his Master of Public Administration degree from the University of Southern California in 1958. He has been City Manager of Dixon since his graduation from USC, but it is widely believed that he will accept a similar position with a larger community within the next year or two. His relations with the City Commission have been excellent, and he is generally regarded as an able and effective administrator.

The City Manager acts as city finance officer as well as personnel director for the more than 1,300 city employees. He has the power to employ all personnel except those of the medical center, the waterworks, the power company, and certain other personnel who are specifically appointed by the City Commission.

Company

The Dixon Power and Light Company was originally a private firm which, in the opinion of many observers, "fell into mismanagement" in the 1950's. In 1962 the City of Dixon purchased the company by revenues generated from the sale of bonds. The remaining outstanding common and preferred stocks are being purchased from general revenues as rapidly as is practical. Total operating revenues were $15.1 million in 1966. Operating expenses were:

Operation	$6,100,000
Maintenance	700,000
Depreciation	1,800,000
	$8,600,000

The Company is under the general operating direction of Miss Jo King, a long-time employee of the Company and resident of Dixon. Miss King holds B.S. and M.S. degrees in Chemical Engineering from Georgia Tech, and has also completed a year of graduate study in Business Management from the University of Virginia. Joining the Company in 1942, Miss King rose steadily through the ranks and was named General Manager in 1965. She will reach the mandatory retirement age in 1973.

Miss King is responsible for preparing and administering the annual budget for the Company. The budget, including all current and capital expenditures, must include detailed information and explanations. Open hearings on the budget are then held before the City Commission gives its approval.

Funds of the Company are kept in local banks, and cash in excess of anticipated current needs is invested in U.S. Treasury Department short-term notes. This policy is consistent with that of the City Manager when dealing with other municipal funds.

Research Program

As elsewhere in the country, citizens protesting the gradual deterioration in air quality became more numerous and more vocal during the early 1960's. Dixon's only newspaper, the Dixon Times Press, was especially active in this regard, having published a series of

strongly worded editorials since 1963. The County was considering the establishment of an "air pollution control board" to be established some time within the next year or two, and the newly-formed "Dixon Citizens for Clean Air" was actively campaigning for anti-pollution legislation by both the City and the County. All the members of the City Commission made public campaign statements promising "to lead the fight against pollution."

In January of 1967, Mr. Siegel learned that the City of Los Angeles was attempting to reduce air pollution by requiring the burning of low-sulfur oil during the winter months at certain of its power generating plants. He then arranged to have a business luncheon with Miss King, and he asked her if this would also be possible in Dixon. "Yes," she replied, "I suppose it would. But the low fuel is a good deal more expensive and I'm not sure that the additional expense is justified. By the way, George, did you know that even high-sulfur oil produces less sulfur dioxide (SO_2) than the coal we're now using? Maybe we simply ought to shift to fuel oil. Period." "Or how about natural gas, Jo?", George suggested. "I know that that would mean putting in a lot of new equipment–storage tanks, pipes, and so on–but maybe that's a good compromise. In any case, why don't we take it up with the Commissioners?"

Mr. Siegel and Miss King appeared at the February meeting of the Commission and outlined their suggestion. There was some discussion by the Commissioners–principally centering on the question of how much pollution would be removed by changing over to a new fuel–and it was then agreed that $10,000 from the Commission's "contingency fund" would be authorized to finance an independent study to determine the appropriate course of action. They directed the City Manager to make the necessary arrangements.

Mr. Siegel then contacted several consulting firms and, in early April, reached a tentative agreement with the Public Systems Engineering Company (PSE), headquartered in Atlanta, for a study to last approximately three calendar months. The Senior Analyst for the PSE would be Mr. Alan Atkinson, a specialist in the engineering-economic analysis of power distribution systems.

The unsigned agreement was then discussed with the Commissioners and, at the April meeting of the Commission, the following resolution was passed:

"WHEREAS it is felt that the citizens of Dixon want some tangible evidence that their city government is taking immediate action to control air pollution, and

WHEREAS there is considerable question as to whether the full legal apparatus for area wide pollution control is not presently available, and

WHEREAS it will take considerable time and cooperation of many agencies to establish the necessary legal apparatus, and

WHEREAS volutnary air pollution abatement requires considerable committee effort, and

WHEREAS the people generally look to city government rather than to industrial corporations as the leaders in air pollution control, and

WHEREAS it is estimated using crude emission factors that the city owned - Dixon Power and Light Company is emitting about 15,000 tons of SO_2 each year from its coal fired furnaces, then,

BE IT RESOLVED that the government of the City of Dixon has the Dixon Power Company furnaces converted to a more pollutant-free fuel to lead the fight against air pollution in the Keener Valley."

Further, it was agreed that, since large expenditures of public funds would be involved in this conversion, a benefit/cost analysis of various engineering approaches to this fuel conversion be prepared by the Public Systems Engineering Company, with the assistance of all relevant public agencies, for review by the city government. It was further suggested that best estimates of the benefit to all taxpayers gained by this reduction in air pollution, including those living in Tiller County, be included within the study.

The study was to be initiated in June, 1967. The time schedule called for completion of the report by September, and if so indicated, change-over to the new fuel in January, 1968.

DATA

Mr. Atkinson met frequently with Mr. Siegel and Miss King, as well as with certain of their subordinates, during June in order to gather the following relevant data for the study.

Demand Distribution

During 1966 the company sold about 900 million kilowatt hours (kwh) of electricity to 64,000 separate customers representing a population of 210,000 people. It is expected that total sales will approximate 950 million kwh in 1967 and 1,000 million kwh in 1968; future demand should increase at the rate of about 50 million kwh per year.

Experience indicates that demand is distributed throughout the year as follows:

Month	% of Total	Month	% of Total
Jan	8.0	Jul	8.6
Feb	8.1	Aug	8.6
Mar	8.2	Sept	8.5
Apr	8.3	Oct	8.3
May	8.5	Nov	8.2
June	8.6	Dec	8.1

These distribution percentages are not expected to change significantly over the foreseeable future.

Alternative Fuels

The Dixon Power and Light Company currently uses power plant grade *coal* obtained from mines in the northwest corner of the state. The coal has an average heat content of 12,700 British thermal units (B.t.u.) per pound and a sulfur content of 1.8% by weight. When ordered in 50-car train lots, this coal has a mine-head price of $5.00 per short ton. Moreover, the railroad charges 1.15 cents per short ton mile for the 50-car train. The mine-head to power plant distance is almost exactly 200 miles.

Bunker C fuel oil may be obtained from a supplier in New Orleans at a price of $2.15 per barrel for lots less than 100,000 barrels (bbls) and $1.90 per bbl for all over 100,000 bbls in a given lot. (For example, a lot of 300,000 bbls would cost 100,000 x $2.15 plus 200,000 x $1.90, or $595,000.) Transportation charges from New Orleans to Dixon are $1.00 per short ton. Bunker C has a heat value of 155,000 B.t.u. per gallon and a sulfur content of 1.5% by weight. Its density is 8.33 lbs. per gallon.

Special low sulfur furnace fuel oil may also be purchased from the same source in New Orleans. The price per barrel is $2.65 for the first 250,000 bbls and $2.40 per bbl for all barrels beyond 250,000 in the same lot. The heat value of this fuel is 150,000 B.t.u. per gallon, its sulfur content is 0.5% by weight, and its density is 8.1 pounds per gallon. As above, the transportation charge between New Orleans and Dixon is $1.00 per short ton.

The Southeastern Gas Transmission Company (SGT) lost a major customer further down the pipe line when a large shipyard was deactivated, and thus SGT is in the unusual position of being able to offer Dixon Power a large quantity of *natural gas* with delivery available immediately.

The heat value of the gas is 1,060 B.t.u. per cubic foot and the sulfur content is 1.7 grains per 1,000 cubic feet.

The contract with the Gas Company would require that SGT offer a guaranteed minimum of 15 x 10^6 thousand cubic feet (mcf) per year. For the five months of December through April, the guaranteed minimum is 1,080 mcf per hour, and for the remaining seven months the minimum is 2,160 mcf per hour. The current contract price is $0.45 per mcf assuming that Dixon Power purchases a minimum of 9 x 10^6 mcf per contract year. This gas contract is renegotiable every ten years.

Hydraulic power is generated only at Orlie Dam, a facility owned by the Georgia Power Company. The Dixon Power and Light Company has no potential hydraulic power resources. Inter-tie power may be purchased from the Georgia Power and Light Company via a five-state inter-tie. Dixon rarely relies on this source, however, since Georgia Power's costs are 15% above Dixon's current levels.

Effects of Air Pollution

Currently, 40,000 home incinerators emit 15,000 tons of gases and dust into the atmosphere each year; 66,000 registered motor vehicles produce another 70,000 tons of various pollutants. To this total, engineers estimate that more than 15,000 tons of sulfur dioxide (SO_2) are added due to the burning of soft coal by the Power Company.[2]

[2] It should be noted that two tons of SO_2 yields one ton of sulfur. The *pollutant*, in this case, is sulfur dioxide.

The air pollution costs to the residents of the community are extremely difficult to measure, although the following estimates were provided by county engineers, health officers, and agricultural extension agents:

Respiratory effects	\$2,000,000/year	
Crop damage	\$5,000,000/year	(at current levels)
Soiling of Property	\$3,000,000/year	

The dollar costs of certain other adverse effects—e.g., reduced visibility—were not estimated.

Based upon these crude estimates of roughly 100,000 tons of pollutants and \$10,000,000 of damage each year, Mr. Atkinson estimated that a reduction of one ton in pollutants will result in a savings to the community of approximately \$100. There were no serious objections to this conclusion from municipal personnel, although many would have preferred a more "supportable" figure. Moreover, in checking other statistics used at the Federal level, Mr. Atkinson believed that this value was "in the ballpark."

Other Assumptions and Operating Characteristics

Power generating equipment currently in use has an effective efficiency rating of 0.30. That is, 100 B.t.u. of heat input will result in only 30 B.t.u. of heat output.

In the event that fuel oil is to be used by the company, storage tanks and associated transfer equipment must be constructed. It is expected that these additional facilities will have a first cost of \$1,000,000, annual maintenance costs of \$50,000, a physical life of 35 years, and zero net terminal salvage value. The maximum net storage capacity of these tanks will be 1,000,000 barrels.

Within the limits of storage capacity, fuel oil will be shipped quarterly from New Orleans, i.e., a shipment every three months.

Existing storage facilities for plant grade coal are sufficient to accommodate more than twice the coal now being used. Thus it is expected that no additional storage facilities will be required over the next 35 years.

During periods of gas shortage, Dixon Power must furnish fuel from its own reserves. To this end, the Company's engineers estimate that a natural gas storage facility and associated distribution equipment may be built on the grounds of the power plant at a cost of \$3,000,000. (Given this storage capacity, the Company may purchase excess gas from SGT during periods of low demand for use during periods of peak demand.) Annual maintenance and other operating costs are expected to be about \$80,000. The facility will have an expected useful life of 35 years with zero net salvage value at the end of that time.

Although many Federal economy studies are conducted using discounting rate in the area of 3-4% per annum, Mr. Atkinson believed that the true "opportunity cost" expressed as an interest rate is more probably twice that number, and thus he decided to use a rate of 7% per annum for their study.

Mr. Atkinson did not feel that projections beyond the year 2000 were justified in view of the high probability of marked relevant technological developments during the next two or three decades, and thus he elected to use a "planning horizon" of 35 years for the benefit-cost analysis.

Before proceeding, Mr. Atkinson checked the "reasonableness" of his assumption with both Miss King and Mr. Siegel. With some very minor differences, they agreed, but they did ask him to test the sensitivity of his conclusions to the assumption prior to submitting his final report to the Commission.

APPENDIX A-1

Some Useful Physical Constants

1 British thermal unit (B.t.u.) = 2.93×10^{-4} kilowatt hours (Kwh)

1 pound (avdp.) = 7,000 grains

1 barrel (bbl) = 42 gallons (gals) as used in oil industry

1 short ton (S.T.) = 2,000 pounds (lbs.)

APPENDIX A-2

Compound Interest Tables

i = 0.07

N	Single Payment		Uniform Annual Series			Gradient Series		N
	Compound Amount CA*	Present Worth PW*	Compound Amount CA	Present Worth PW	Capital Recovery CR	Uniform Series USG	Present Worth PWG	
1	1.070	0.9346	1.000	0.935	1.07000	0.000	0.000	1
2	1.145	0.8734	2.070	2.808	.55309	0.483	0.873	2
3	1.225	0.8163	3.215	2.624	.38105	0.955	2.506	3
4	1.311	0.7629	4.440	3.387	.29523	1.416	4.795	4
5	1.403	0.7130	5.751	4.100	.24389	1.865	7.647	5
6	1.501	0.6663	7.153	4.767	.20980	2.303	10.978	6
7	1.606	0.6227	8.654	5.389	.18555	2.730	14.715	7
8	1.718	0.5820	10.260	5.971	.16747	3.147	18.789	8
9	1.838	0.5439	11.978	6.515	.15349	3.552	23.140	9
10	1.967	0.5083	13.816	7.024	.14238	3.946	27.716	10
11	2.105	0.4751	15.784	7.499	.13336	4.330	32.466	11
12	2.252	0.4440	17.888	7.943	.12590	4.703	37.351	12
13	2.410	0.4150	20.141	8.358	.11965	5.065	42.330	13
14	2.579	0.3878	22.550	8.745	.11434	5.417	47.372	14
15	2.759	0.3624	25.129	9.108	.10979	5.758	52.446	15
16	2.952	0.3387	27.888	9.447	.10586	6.090	57.527	16
17	3.159	0.3166	30.840	9.763	.10243	6.411	62.592	17
18	3.380	0.2959	33.999	10.059	.09941	6.722	67.622	18
19	3.617	0.2765	37.379	10.336	.09675	7.024	72.599	19
20	3.870	0.2584	40.995	10.594	.09439	7.316	77.509	20
21	4.141	0.2415	44.865	10.836	.09229	7.599	82.339	21
22	4.430	0.2257	49.006	11.061	.09041	7.872	87.079	22
23	4.741	0.2109	53.436	11.272	.08871	8.137	91.720	23
24	5.072	0.1971	58.177	11.469	.08719	8.392	96.254	24
25	5.427	0.1842	63.249	11.654	.08581	8.639	100.676	25
26	5.807	0.1722	68.676	11.826	.08456	8.877	104.981	26
27	6.214	0.1609	74.484	11.987	.08343	9.107	109.166	27
28	6.649	0.1504	80.698	12.137	.08239	9.329	113.226	28
29	7.114	0.1406	87.347	12.278	.08145	9.543	117.162	29
30	7.612	0.1314	94.461	12.409	.08059	9.749	120.972	30
31	8.145	0.1228	102.073	12.532	.07980	9.947	124.655	31
32	8.715	0.1147	110.218	12.647	.07907	10.138	128.212	32
33	9.325	0.1072	118.933	12.754	.07841	10.322	131.643	33
34	9.978	0.1002	128.259	12.854	.07780	10.499	134.951	34
35	10.677	0.0937	138.237	12.948	.07723	10.669	138.135	35
40	14.974	0.0668	199.635	13.332	.07501	11.423	152.293	40
45	21.002	0.0476	285.749	13.606	.07350	12.036	163.756	45
50	29.457	0.0339	406.529	13.801	.07246	12.529	172.905	50
55	41.315	0.0242	575.929	13.940	.07174	12.921	180.124	55
60	57.946	0.0173	813.520	14.039	.07123	13.232	185.768	60

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Part B: Analysis

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ANALYSIS

In keeping with the terms of the agreement with the City, Mr. Atkinson developed a benefit-cost analysis of the four alternatives under consideration: (1) coal, (2) Bunker C fuel oil, (3) low sulfur fuel oil, and (4) natural gas.

The principal elements included in the study were the basic cost of the fuel at the point of origin, cost to transport the fuel from the source to the power plant in Dixon, cost of additional storage, if any, and the cost to the community of the pollution caused by burning the fuel. He realized that there were some additional consequences, of course, but these would be omitted from the economic portion of the analysis either because they were too difficult to reduce to equivalent monetary terms or because they did not seem to be especially significant.

Demand for Fuel (base year)

The first step was the determination of the expected demand for fuel during the first (base) year of the "planning horizon," or the year 1968. Based on requirements of 1,000 million kilowatt-hours, the demand for equivalent *heat output* is:

$$1{,}000 \times 10^6 \text{ kwh} \times \frac{1 \text{ B.t.u.}}{2.93 \times 10^4 \text{ kwh}} = 3{,}413 \times 10^9 \text{ B.t.u.}$$

If the power generators operate at 30% efficiency, the *heat input* will be:

$$\frac{1}{0.30} \times 3{,}413 \times 10^9 \text{ B.t.u.} = 11{,}400 \times 10^9 \text{ B.t.u.}$$

Now, to determine the amount of fuel required to generate this equivalent amount of heat:

Coal

$(11{,}400 \times 10^9 \text{ B.t.u.}) \times (1 \text{ lb}/12{,}700 \text{ B.t.u.}) = 898 \times 10^6 \text{ lbs}$

$(898 \times 10^6 \text{ lbs}) \times (1 \text{ ton}/2{,}000 \text{ lbs}) = 449{,}000 \text{ tons}$

Fuel Oil (Bunker C)

$(11{,}400 \times 10^9 \text{ B.t.u.}) \times (1 \text{ gal}/155{,}000 \text{ B.t.u.}) = 73.5 \times 10^6 \text{ gals}$

$(73.5 \times 10^6 \text{ gals}) \times (1 \text{ bbl}/42 \text{ gals}) = 1{,}750{,}000 \text{ bbls}$

Fuel Oil (low sulfur)

$(11{,}400 \times 10^9 \text{ B.t.u.}) \times (1 \text{ gal}/150{,}000 \text{ B.t.u.}) = 76.0 \times 10^6 \text{ gals}$

$(76.0 \times 10^6 \text{ gals}) \times (1 \text{ bbl}/42 \text{ gals}) = 1{,}809{,}000 \text{ bbls}$

Natural Gas

$$(11{,}400 \times 10^9 \text{ B.t.u.}) \times (1 \text{ ft}^3/1{,}060 \text{ B.t.u.}) = 10.75 \times 10^9 \text{ ft}^3 = 10.75 \times 10^6 \text{ mcf}$$

Parenthetically, at this point, Mr. Atkinson noted that the natural gas requirement in the base year, 10.75 million mcf, would be well in excess of the 9 million mcf which would have to be guaranteed as a minimum purchase during the contract year.

Fuel Costs (base year)

Based upon an expected price of \$5.00 per short ton, the cost of 449,000 tons of coal in 1968 would be \$2,245,000.

It was assumed that Bunker C fuel oil would be shipped quarterly, within the limits of storage capacity. Since the total expected demand in 1968 is 1,750,000 bbls, Mr. Atkinson concluded that quarterly shipments of, say, 437,500 bbls would not exceed tank capacity. Thus total cost of fuel in the base year is determined as follows:

100,000 bbls @ \$2.15/bbl =	\$ 215,000
337,500 bbls @ \$1.90/bbl =	641,250
Fuel cost per shipment =	\$ 856,250
	x 4
Fuel cost for the year =	\$3,425,000

In like manner, if the 1,809,000 bbls of low sulfur fuel oil were purchased in four equal lots of 452,250 bbls each, the total cost for the year would be:

250,000 bbls @ \$2.65 =	\$ 662,500
202,250 bbls @ \$2.40 =	485,400
Fuel cost per shipment =	\$1,147,900
	x 4
Fuel cost for the year =	\$4,591,600

Finally, at \$0.45 per thousand cubic feet, the total cost in the base year for 10.75×10^6 mcf would be \$4,837,500.

Transportation Costs (base year)

Based upon an estimated cost of \$0.0115 per ton-mile, the cost to ship 449,000 tons of coal 200 miles would be \$1,032,700.

Bunker C fuel oil has a density of 8.33 pounds per gallon, and thus 73.5 million gallons represents 612 million pounds, or 306,000 short tons. Assuming costs of \$1.00 per ton, the expected transportation costs in the base year would be \$306,000.

The transportation costs in 1968 for low sulfur fuel oil were computed in the same manner, except in this instance the density of the oil is only 8.1 pounds per gallon. Thus:

$$(8.1 \text{ lbs/gal}) \times (76.0 \times 10^6 \text{ gals}) = 616 \times 10^6 \text{ lbs}$$

$$= 308{,}000 \text{ tons}$$

$$308{,}000 \text{ tons @ } \$1.00\text{/ton} = \$308{,}000$$

Transportation costs for natural gas were considered to be negligible since pipe lines to the City already were in place. Moreover, the cost of any necessary auxiliary local equipment would be borne largely by the Gas Company.

Cost Increases due to Growth

Base year costs were then adjusted to reflect the expected annual increase of 50 million kilowatt-hours. Since this represents a linear growth of 5% per year over the 1968 demand of 1,000 million kwh, the fuel cost adjustments were determined as follows:

Coal: 0.05 x \$2,245,000 = \$112,250 per year.

Fuel Oil (Bunker C): 0.05 x 1,750 bbls = 87,500 bbls
87,500 x \$1.90/bbl = \$166,250 per year.

Fuel Oil (Low Sulfur): 0.05 x 1,809,000 bbls = 90,450 bbls
90,450 x \$2.40/bbl = \$217,080 per year.

Natural Gas: 0.05 x \$4,837,500 = \$241,875 per year.

Similarly, the annual increase in transportation costs would be expected to be:

Coal: 0.05 x \$1,032,700 = \$51,635

Fuel Oil (Bunker C): 0.05 x \$306,000 = \$15,300

Fuel Oil (Low Sulfur): 0.05 x \$308,000 = \$15,400

Natural Gas: (none)

Thus the expected total annual increase in the cost of fuel, including transportation, was determined by Mr. Atkinson to be:

	Coal	Fuel Oil (Bunker C)	Fuel Oil (Low Sulfur)	Natural Gas
Fuel	\$112,250	\$166,250	\$217,080	\$241,875
Transportation	51,635	15,300	15,400	– 0 –
Totals	\$163,885	\$181,550	\$232,480	\$241,875

Storage Costs (Annualized)

No additional storage costs for coal will be required over the 35-year planning horizon.

Mr. Atkinson assumed that storage costs for fuel oil would be equal for both Bunker C and low sulfur fuel oil since the annual requirements for each, by volume, would be practically the same. The capital cost for the storage facilities, expressed as an equivalent annual cost, was found by multiplying the initial cost by the Capital Recovery Factor using an interest rate (i) of 7% and project life (n) equal to 35 years. (See Appendix A-2.) Thus:

$$\text{Capital Recovery} = \$1{,}000{,}000\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$$

$$= \$1{,}000{,}000\ (0.07723)$$

$$= \$77{,}000$$

Adding the annual maintenance and operating costs ($50,000), the equivalent uniform annual cost (EUAC) was determined to be *$127,000.*

The storage cost for natural gas was found in a similar manner. Here, the initial capital cost "spread" over a 35-year period, at an interest rate of 7%, was found to be:

$$\text{Capital Recovery} = \$3{,}000{,}000\ (0.07723)$$

$$= \$232{,}000$$

$$\text{and EUAC} = \$232{,}000 + \$80{,}000$$

$$= \$312{,}000$$

Air Pollution Damage (base year)

The sulfur content of the *coal* currently being used by the Company is 1.8% by weight, and thus 449,000 tons of coal to be consumed in 1968 would yield 8,080 tons of sulfur, or 16,160 tons of sulfur dioxide (SO_2). At an assumed damage cost of $100 per ton of contaminant, this would result in approximately $1,616,000 in damages as measured in monetary terms.

Mr. Atkinson determined the base year damage costs for the other three contaminants as follows:

Fuel Oil (Bunker C) – Sulfur content, 1.5% by weight

0.015 x 306,000 tons = 4,590 tons of sulfur, or

= 9,180 tons of SO_2

9,180 tons @ $100/ton = $918,000

Fuel Oil (low sulfur) – Sulfur content, 0.5% by weight

0.005 x 308,000 tons = 1,540 tons of sulfur, or

= 3,080 tons of SO_2

3,080 tons @ $100/ton = $308,000

Natural Gas – Sulfur content, 1.7 grains per mcf

(1.7 grains/mcf) x (1 lb/7,000 grains)

$= 0.242 \times 10^{-3}$ lbs/mcf

$= 2.6 \times 10^{3}$ lbs of sulfur, or

= 2.6 tons of SO_2

Air Pollution Annual Increase due to Growth

Mr. Atkinson assumed that the equivalent dollar cost of air pollution damage due to power plant fuel burning will increase from year to year in direct proportion to the increase in power consumption. As we noted earlier, this represents a linear growth rate of 5% per year over the base year, 1968. Thus the annual increase for each of the alternatives was assumed to be:

Coal: 0.05 x $1,616,400 = $80,820

Fuel Oil (Bunker C): 0.05 x $918,000 = $45,900

Fuel Oil (Low Sulfur): 0.05 x $308,000 = $15,400

Natural Gas: 0.05 x $260 = $13 ... (assumed to be negligible)

Equivalent Uniform Annual Costs (Fuel, Transportation, Storage)

The year-by-year growth in fuel and transportation costs was first converted to an equivalent uniform annual value by use of the "uniform series gradient factor" as given in Appendix A-2. The value of this factor for i = 7% and n = 35% is 10.67.

To illustrate this procedure, recall that, in the case of coal, the annual increase in costs of fuel and transportation was expected to be $163,885, and the base year values for 1968 were $2,245,000 (fuel) and $1,033,000 (transportation). The expected year-by-year cash flows, then, are as follows:

Year of Planning Horizon	Cost: Fuel	Cost: Transportation	Increase in Fuel and Transportation Costs
1	$2,245,000	$1,033,000	– 0 –
2	2,245,000	1,033,000	163,885
3	2,245,000	1,033,000	2 x 163,885
.	.	.	.
.	.	.	.
.	.	.	.
35	2,245,000	1,033,000	34 x 163,885

To convert the last column to an equivalent uniform annual cost, Mr. Atkinson simply multiplied the annual "gradient," $163,885, by the appropriate Uniform Series Gradient Factor, 10.67.* The result, $1,749,000, was then added to the base year values as previously determined so as to find the total cost, other than air pollution, for this alternative.

In tabular form, the equivalent uniform annual cost, other than air pollution, for each of the alternatives was determined as follows:

	Coal	Fuel Oil (Bunker C)	Fuel Oil (Low Sulfur)	Natural Gas
Annual increase	$ 163,885	$ 181,550	$ 232,480	$ 241,875
Gradient factor	10.67	10.67	10.67	10.67
Annual equivalent	$1,749,000	$1,937,000	$2,481,000	$2,580,000
Base year values				
Fuel	2,245,000	3,425,000	4,592,000	4,838,000
Transportation	1,033,000	306,000	308,000	– 0 –
Storage	– 0 –	127,000	127,000	312,000

The equivalent uniform annual costs for air pollution were determined in a similar manner:

	Coal	Fuel Oil (Bunker C)	Fuel Oil (Low Sulfur)	Natural Gas
Annual increase	$ 80,820	$ 45,900	$ 15,400	negligible
Gradient factor	10.67	10.67	10.67	10.67
Annual equivalent	$ 822,000	$ 490,000	$ 164,000	–
Base year value	$1,616,000	$ 918,000	$ 308,000	negligible
	$2,438,000	$1,408,000	$ 472,000	–

The Benefit-Cost Analysis

Having converted all expected (monetary) consequences of the four alternatives to equivalent uniform annual costs, Mr. Atkinson was now ready to proceed with the benefit-cost analysis. First he defined "incremental costs" for the benefit-cost ratio as the difference between the fuel-transportation-storage costs of a pair of alternatives; "incremental benefits" were measured by the reduction in air pollution costs between the alternatives.

Comparing fuel oil (Bunker C) with coal:

		$5,795,000
		-5,027,000
Incremental costs	=	$ 768,000

*The use of "gradient factors" is discussed in a number of texts. One such reference is *Principles of Engineering Economy*, by E. L. Grant and W. G. Ireson, 4th ed. revised, Ronald Press, pp. 80-82.

		\$2,438,000
		- 1,408,000
Incremental benefits	=	\$1,030,000
Benefit-Cost Ratio	=	\$1,030,000/\$768,000 = *1.34*

Thus "Bunker C," he concluded, is preferable to "coal" since the ratio exceeds unity.

Comparing fuel oil (low sulfur) to fuel oil (Bunker C):

		\$7,508,000
		- 5,795,000
Incremental costs	=	\$1,713,000
		\$1,408,000
		- 472,000
Incremental benefits	=	\$ 936,000
Benefit-Cost Ratio	=	\$936,000/\$1,713,000 = *0.55*

Thus "low sulfur" is *not* preferable to "Bunker C" since the ratio is less than unity.

Comparing natural gas to fuel oil (Bunker C):

		\$7,730,000
		- 5,795,000
Incremental costs	=	\$1,935,000
		\$1,408,000
		–
Incremental benefits	=	\$1,408,000
Benefit-Cost Ratio	=	\$1,408,000/\$1,935,000 = *0.73*

Thus "natural gas" is *not* preferable to fuel oil (Bunker C),

and

BUNKER C FUEL OIL IS THE MOST ECONOMICAL FUEL.

Sensitivity Analysis

Mr. Atkinson was aware of the substantial uncertainty associated with the \$100 per ton estimate of the cost of pollution. He noted that, although natural gas is more expensive than Bunker C fuel oil, its principal advantage lies in its effect on air pollution. He anticipated the question, "At what assumed value for 'air pollution damage cost per ton of SO_2 pollutant'

would natural gas be a more economic fuel than Bunker C fuel oil?" Letting x be this break-even value, the analysis proceeded as follows:

$$\text{Pollution cost (Bunker C)} = 9{,}180x + (0.05)(9{,}180x)(10.67)$$
$$= 9{,}180x + 4{,}898x$$
$$= 14{,}078x$$

$$\text{Pollution cost (natural gas)} = 3x + (0.05)(3x)(10.67)$$
$$= 3x + 2x$$
$$= 5x$$

$$\text{B:C (gas vs. Bunker C)} > 1.00$$

$$\frac{14{,}078x\text{-}5x}{\$7{,}730{,}000\text{-}\$5{,}795{,}000} > 1.00$$

$$\frac{14{,}073x}{\$1{,}935{,}000} > 1.00$$

$$x > \frac{\$1{,}935{,}000}{14{,}073}$$

$$x > \$137$$

Thus, if the air pollution cost per ton is greater than \$137, rather than the \$100 value assumed originally, natural gas would be economically preferable to Bunker C fuel oil. But since Mr. Atkinson did not feel that the original assumption was in error by more than 15-20%, he concluded that the solution was relatively insensitive to this estimate. However, he did include the results of this sensitivity analysis, along with a discussion of the expected non-monetary consequences, in the final report presented to the Commission on September 1, 1967.

APPENDIX B-1

ADDITIONAL PROBLEMS

1. In the event that fuel oil is used, it is expected that storage tanks will be built immediately having a capacity of 1,000,000 barrels. Does this seem reasonable? What would be the economic effect of building a smaller capacity now and enlarging capacity as demand grows? Demonstrate with a numerical example.

2. What is the economic effect if the gas storage facilities are to be expanded or replaced at the end of 20 years (rather than 35 years as originally stated)?

3. What is your opinion of the way in which "benefits" are measured? Is the solution sensitive to the initial estimate of $100/ton?

4. Do you believe that the forecast of population growth and power consumption appears reasonable? In what manner will various population growth rates affect the benefit-cost analysis? Note that estimates of exponential (rather than linear) growth in power consumption create additional computational complexity.

5. Note the "linearity assumption" concerning the economic effect of air pollution, i.e., a ton of pollutant causes $100 in damage, regardless of whether it is the first ton or the 1,000th ton. Discuss the reasonableness of this assumption.

6. The study assumes that "damage costs" per ton of pollutant are the same for sulfur as for other causes. Discuss the reasonableness of this assumption.

7. Conduct sensitivity analyses for interest rate, population growth and cost of fuel.

8. Use the benefit-cost ratio method to determine which of the following two alternatives is preferable.

Alt.	Benefits	Costs
A	$12	$ 8
B	$16	$11